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TRANSMITTAL

TO:	DATE	PROJECT NO.
Jennifer Fitch, PE Project Manager Vermont Agency of Transportation	8/22/2014	Brookfield BRF FLBR (2)

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1		FRP Fabrication NCR 7-1	H

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BY: Paul [signature]

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August 21, 2014

Mr. Paul Holloway
Miller Construction, Inc
PO Box 86
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Brookfield BRF FLBR (2)

Dear Mr. Holloway:

Background

In a letter dated August 13, Kenway provided additional photos and quantification of several dry spots on Pontoon 3 as requested by T. Y. Lin in a letter dated August 12. Kenway has also provided to T. Y. Lin documents that demonstrate re-infusion of local dry areas is accepted by the American Bureau of Shipping and the U.S. Navy for repairing composite hull structure.

In a response letter dated August 19, T. Y. Lin requested that a formal test program be developed and executed by Kenway to demonstrate adequate strength, stiffness, and durability of secondary infusions.

Defect Summary

A measurement method was developed and used to quantify the depth of dry fabric in poorly infused areas. The average thickness of the fully infused hull laminate in the vicinity of the defects, as measured using a UT thickness gauge, is 0.607 in. This value is used in conjunction with the dry fabric thickness to provide the approximate thickness of wet out laminate behind dry fabric. As indicated in Table 1 and shown in Kenway letter dated August 13, the minimum thickness of primary infused laminate along the defect centerline is 1/4 in. at the single worst point (located behind the bonded FRP blister) and otherwise greater than 3/8 in. With the exception of a section along the 6 in. flange, all dry areas are centered directly above the rod holes.

Table 1 – Dry Fabric and Wet Laminate Thickness

Location	Max Dry Depth	Mean Dry Depth	Min Resin Thick	Mean Resin Thick
West, Radius	0.251	0.163	0.356	0.444
Middle, Radius	0.155	0.107	0.452	0.500
Mid/East, Radius	0.056	0.056	0.551	0.551
East, Radius	0.356	0.215	0.251	0.392
East, Vertical	0.012	0.012	0.595	0.595
Middle, Vertical	0.024	0.024	0.583	0.583
West, Vertical	0.034	0.034	0.573	0.573

Defect Impact

After reviewing all submitted and approved calculations of the FRP rafts, no calculation was identified or evaluated where the strength or stiffness of the radius wall was a controlling factor in the design. For operational load cases, it was established that flexural stresses are resisted by the top and bottom plates, shear loads are resisted by the internal bulkheads/vertical wall, and bolt loads only exist in the thickened flange areas.

Subsequently, the raft has been revisited as a composite section subjected to maximum vertical bending moment (Strength V, top in tension) with the stress computed just below the base of the flange. Assuming the entire “East, radius” secondary laminate is ignored in the stiffness calculation, the resulting stress is calculated to be 2,681 psi and the factored tensile strength is ($\lambda\phi F_T$) 23,219 psi. The reserve capacity is still 8.7 times the design load and, put another way, the tensile stress is 7% of the ultimate strength (2,681 / 39,690) when using only the primary infused thickness.

$$f_T = \frac{M_u y}{I}$$

$$M_u = 1{,}612 kip \cdot ft$$

$$I = 103{,}511 in^4$$ (ignoring secondary infusion – was 104,251)

$$\lambda = 0.9$$

$$\phi = 0.65$$

$$y = 14.35 in$$ (35 - 20.65)

Ice loading was previously evaluated on the radius wall in terms of flexure between bulkheads. As noted above, the partial thickness dry areas are located directly above the rod holes and are backed by a 3 in. wide by 1/2 in. thick bonded bulkhead flange. The maximum shear at the supports (bulkheads) for a 22.2 psi ice load is 139 lb/in as previously documented using beam on elastic foundation equations (elastic foundation being the flotation foam). The laminate design shear strength ($\lambda\phi V_n$) is 1,349 lb/in using a thickness of 0.357 in. (the minimum primary thickness beyond the bonded FRP blister envelope). Discounting the secondary infusion completely would still provide a reserve capacity of 9.7 times the design load. Alternately stated, the shear loading is only 2% of ultimate shear strength (139 / 6,000).

$$V_n = F_{LT} t$$

$$F_{LT} = 6.0 ksi$$ (through thickness shear strength)

$$\lambda = 0.9$$

$$\phi = 0.7$$

$$t = thickness, in$$

Constant, through thickness compression loading induced by post-tensioned threaded rods will be imparted on the repaired laminate. However, primary and secondary infusions are parallel to each other and perpendicular to the load and transverse bulkhead. Therefore, the imposed stresses are acting to hold the laminate together. Also, an 8 in. square FRP blister is bonded to the exterior surrounding the hole. The compressive strength of the laminate, shown during design submittals to be 531% greater than design requirements, would resist the applied compression loads even if the secondary infused laminate was completely disbonded from the primary laminate. In reality, the secondary resin is bonded to the primary resin and continuous fiber extends throughout the area across the bond.

In order to empirically evaluate the long term effect of cyclic loading on the durability of the re-infusion, the direction and magnitude of applicable loads must first be defined. After reviewing the design, Kenway has determined that the quantifiable cyclic loads imparted on the repair areas will be due to ice loading where the load is one sided (compression only) or service loads where the load is fully reversed (tension and compression). Figure 1 shows curve fits to data for vinyl ester infused fiberglass specimens that have been exposed to fatigue loading. This shows that the laminate can be exposed to 50% of its ultimate compressive strength (R = 10) and 25% of its ultimate tensile strength (R = -1) and still reach 1 million cycles before failure. By comparison, the primary laminate in way of defects – completely ignoring the secondary infusion – will see 7% of the ultimate tensile strength and 2% of the ultimate shear strength.

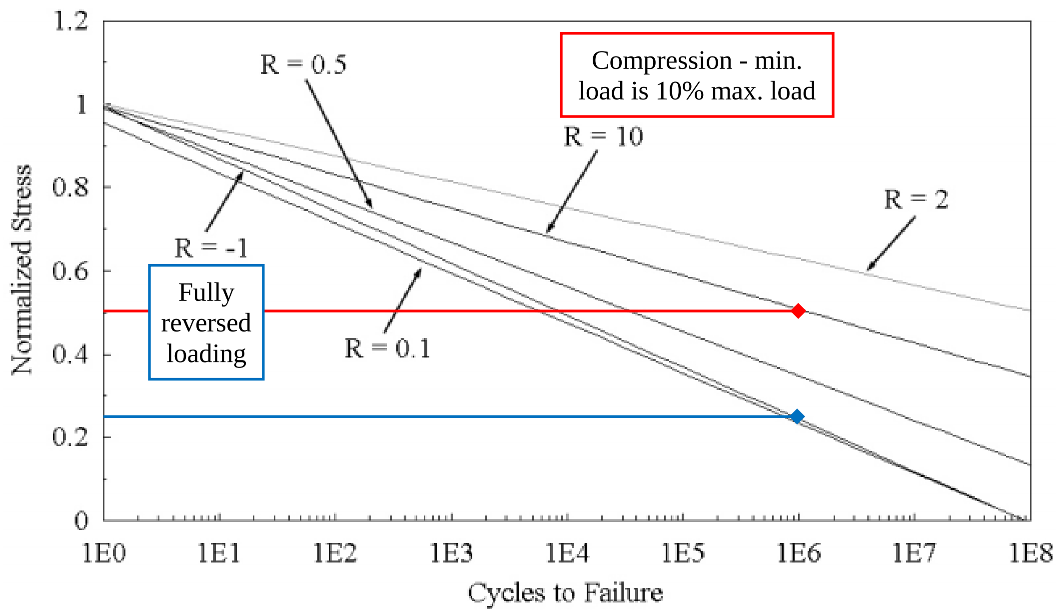

Figure 35. Normalized Fatigue Models, Exponential Regression Including All Data.

Figure 1 – Constant Amplitude S-N Fatigue Data[1]

Summary

Based on the following points, Kenway requests that VTrans and T. Y. Lin reconsider the need to develop a laboratory testing plan that attempts to quantify the impact of reinfusion.

- Quantifiable quasi-static stresses on the primary infused laminate – ignoring the secondary infusion completely – are well below the allowable design strengths as documented above.
- Quantifiable cyclical stresses on the primary laminate – ignoring the secondary infusion completely – and the anticipated number of cycles in service are orders of magnitude lower than documented S-N curves for vinyl ester/fiberglass laminate.

[1] Wahl, N.K., Mandell, J.F., Samborsky, D.D., "Spectrum Fatigue Lifetime and Residual Strength for Fiberglass Laminates," Sandia Report SAND2002-0546, March 2002.

- Very low stresses (less than 10%) relative to allowable strength are not sufficient to cause delamination between primary and secondary infusions. Regardless, there is at least 3/8” of solid primary laminate across the entire hull, which would prevent any leakage from occurring during service.
- ABS NVR and similar guides allow the reinfusion of local dry laminate “with engineering concurrence,” which is provided herein.
- The repaired areas are backed up by an additional 1/2 in. of laminate in the form of the bonded transverse bulkheads.
- Kenway is willing to warranty these specific reinfusion repairs if they are the source of leaking in the future.

Sincerely,

Jacob Marquis

Jacob Marquis, P.E.
Senior Project Engineer